NEUTRAL GROUNDING RESISTOR MONITORING

WHITE PAPER

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INTRODUCTION

Resistance grounding prevents many of the problems that are associated with ungrounded and solidly grounded electrical distribution and utilization systems. Resistance grounding can limit point-of-fault damages, eliminate transient overvoltages, reduce arc-flash hazards, limit voltage exposure to personnel, and provide adequate tripping levels for selective current-based ground-fault detection and coordination.

This white paper reviews charging current, ground-fault detection, and ground-fault coordination. It also presents reasons for monitoring the neutral grounding resistor (NGR). Finally, this paper discusses the problems that are associated with NGR monitoring and summarizes their design requirements.

CHARGING CURRENT

Each phase of a distribution system has capacitance to ground. Although a system may be ungrounded in that none of its current-carrying conductors are intentionally connected to ground, an ungrounded system has its neutral point established by distributed system capacitance (see **Figure 1**). If capacitive reactance is balanced, voltages and currents are balanced (see **Figure 1A**). If phase A is faulted to ground, the voltage and current to ground in phases B and C will be 1.73 times larger than when they were balanced. Fault current is the system charging current and its magnitude is three times the magnitude of the unfaulted phase-to-ground current.

Extensive damage can occur when an ungrounded power-distribution system experiences a transient-overvoltage condition caused by an intermittent ground fault. An NGR with a let-through current equal to or greater than the system charging current eliminates transient overvoltages. **Figure 2** shows the same system as **Figure 1**, but with a 5.0 A-NGR. Voltages and currents in the unfaulted case are the same as in the ungrounded system. If phase A is faulted to ground, then the voltages and currents in phases B and C will also be the same as that in the ungrounded system. Their fault current, however, will be the vector sum of the NGR current and system charging current.

If the system in **Figure 2** has three equal feeders, currents will be as shown in **Figure 3**. Meters A1 and A3 on the unfaulted feeders each read the charging current of their respective feeders, 1.0 A. The NGR current and fault current remain unchanged at 5.0 A and 5.8 A respectively. Meter A2 on the faulted feeder will read 5.4 A—the vector sum of the NGR current and the charging currents of the unfaulted feeders.

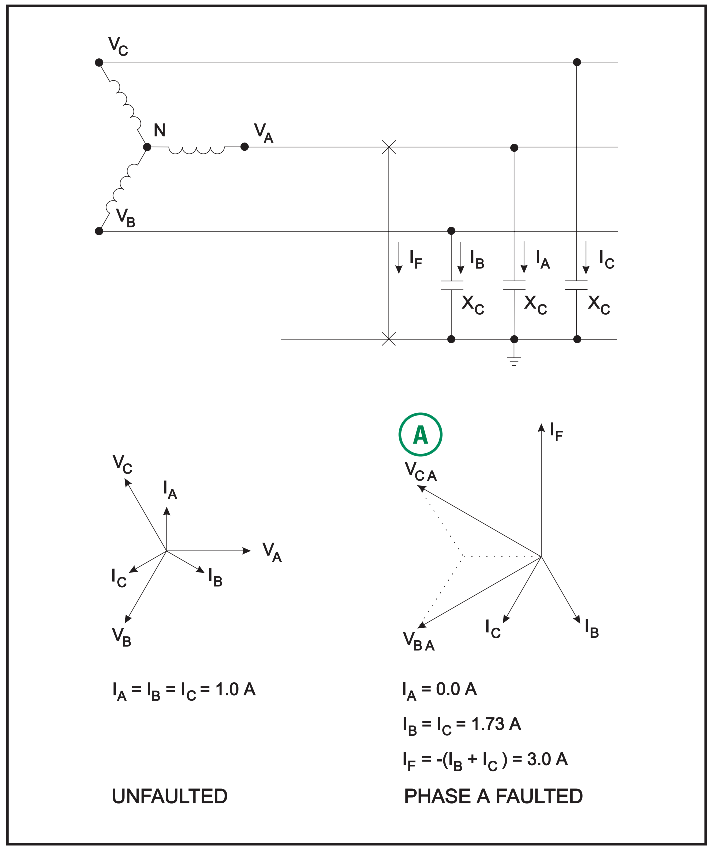


Figure 1. Ungrounded system.

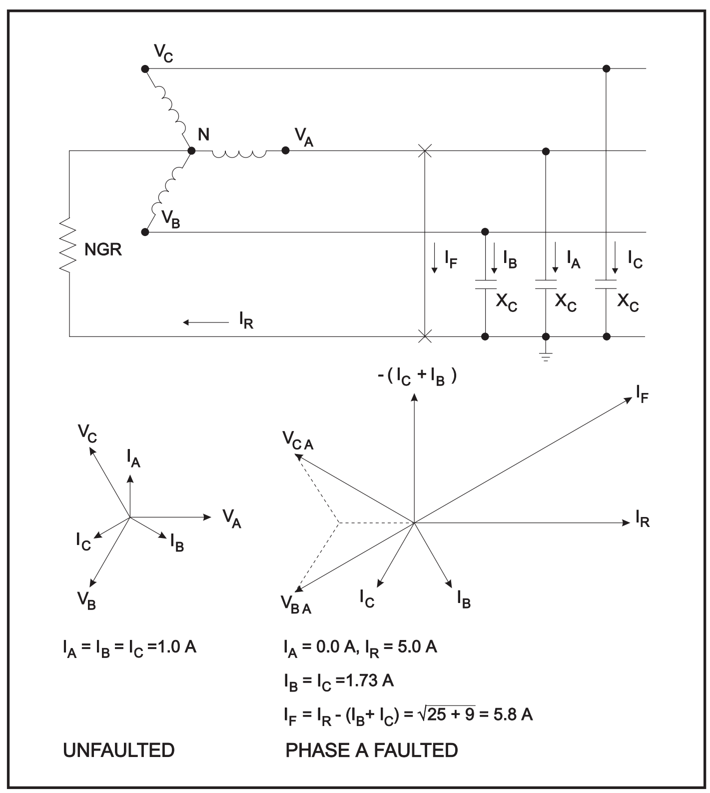


Figure 2. Resistance-grounded system.

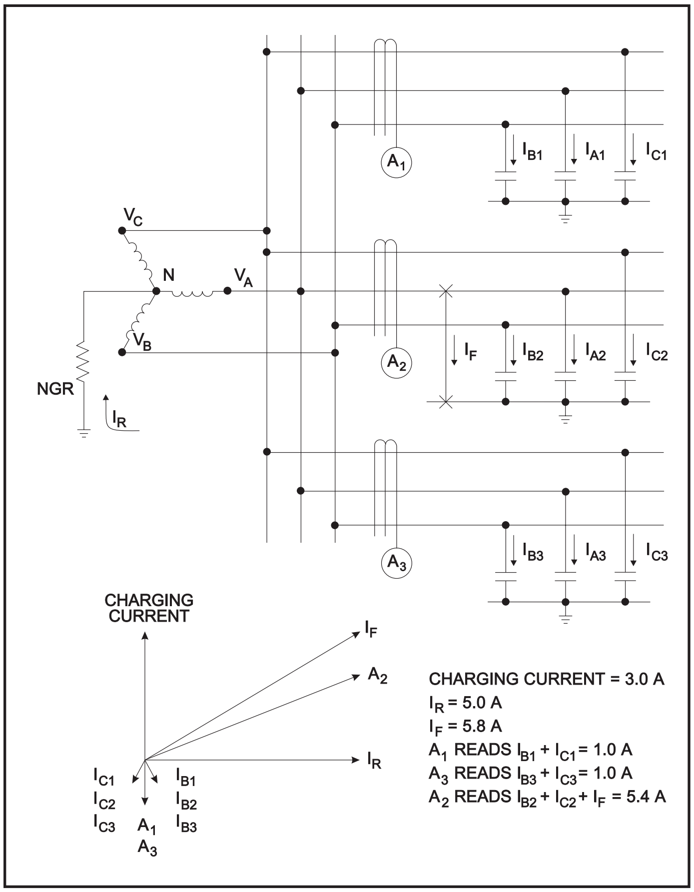


Figure 3. Resistance-grounded system with one faulted feeder.

SELECTIVE GROUND-FAULT COORDINATION

Selective ground-fault coordination is achieved if sympathetic tripping cannot occur and only the faulted feeder is removed from the system. It has just been shown that a ground-fault detector on an unfaulted feeder observes the feeder's charging current when a ground fault occurs elsewhere in the system. Consequently, sympathetic tripping can occur on an unfaulted feeder if the operating value of the feeder's ground-fault relay is less than the feeder's charging current. Sympathetic tripping cannot occur, regardless of the relative feeder sizes, if an operating value above the charging current of the largest feeder is used for all ground-fault relays in the system. To provide a margin, selective ground-fault coordination is usually achieved with time discrimination and an operating value above the system charging current. Backup protection is accomplished either by time-delayed operation of an upstream device or by a zone-selective interlock that blocks the upstream device from tripping for a pre-selected time.

TRIPPING RATIO AND NGR SELECTION

Tripping ratio is the ratio of prospective ground-fault current to the operating value of the ground fault protection. An adequate tripping ratio ensures that a sufficient ground-fault current is available for detection when a ground fault occurs. A tripping ratio of at least 7 is necessary to detect a two-phase-to-ground fault [2]. Some people mistakenly believe that a two-phase-to-ground fault must be cleared by overcurrent devices and that ground-fault detection does not require a tripping ratio of 7. However, a higher tripping ratio is necessary to provide machine-winding ground-fault protection. A commonly accepted protection philosophy is based on protecting 90 percent of a wye-connected winding and that the probability of a ground fault on the last 10 percent nearest the neutral is small [3]. Even though there must be a tripping ratio of 10 to meet this philosophy for protection, tripping ratios of 5 are common.

If the operating value of the ground-fault relays is greater than the system charging current and a tripping ratio of 5 is selected (which ensures adequate tripping levels and machine-winding ground-fault protection), then the let-through current of the NGR must be greater than 5 times the system charging current. Charging current is a function of system voltage and can be measured on an existing system or estimated from tables. Typically, charging current will be 0.5 A per 1000 kVA on low-voltage systems and 1.0 A per 1000 kVA on medium-voltage systems. Consequently, 5 A, 15 A, and 25 A-grounding resistors are common.

Low-current NGRs are used where the energy available to a ground fault, or where the voltage drop in the ground return, must be limited. Large systems use high-current NGRs. Designers who are comfortable with solidly grounded systems often choose NGRs with the let-through currents much larger than necessary for either system stability or selective coordination.

NGR SELECTION FOR ALARM-ONLY SYSTEMS

Some electrical codes allow for continued operation of a system when one phase is faulted to ground. There may be restrictions on system voltage and ground-fault current, and there may be a requirement to locate and isolate the fault as quickly as practical.

For an alarm-only system, choose an NGR with a let-through current larger than the system charging current. The pickup current of ground-fault devices is usually set at or below 50 percent of the NGR let-through current.

NGR MONITORING CONSIDERATIONS

The proceeding sections outline a method for NGR sizing for low and medium voltage installations.

While other requirements can influence NGR sizing, however, ground-fault protection, coordination and annunciation systems depend on the integrity of the NGR. If the NGR fails open, these protective systems become inoperative, the system becomes ungrounded, and exposure to transient overvoltages is possible. If the effective resistance of the NGR decreases, such as during a fault to ground at the neutral point of the transformer, a fault to ground on a distributed neutral conductor or an inadvertent short across the NGR, then the system becomes low-resistance or solidly grounded, and high levels of fault current are possible.

One approach to establishing design requirements is to analyze designs for conceptual problems or hazards. The use of a potential transformer as an NGR monitor is ideal for this approach. For example, some installations simply connect the primary of a potential transformer across the NGR and connect the secondary to a time-delay relay. This is a voltage-based ground-fault detector and it does not monitor the NGR. Rather, it monitors the neutral voltage and it will not operate until a ground fault occurs, regardless of the NGR's condition. If the NGR is open when a ground fault occurs, then the ground-fault relays will not operate and the neutral voltage will be sustained until the time-delay relay operates and trips the breaker. A ferroresonance hazard exists with this technique. If the NGR opens, the system is grounded through the potential transformer and its inductance can interact with system capacitance to form a series RLC resonant circuit [4] [5].

Another problem that potential transformer installations present is when a ground fault through a rectifier element exists. The transformer winding will provide a low resistance path to direct current which can saturate the transformer. This will affect the transformer's operation or potentially burn the windings. This same problem exists in installations that use neutral grounding transformers. In both cases, direct current is not limited and ground fault voltages can be higher than anticipated.

Although inrush is more problematic with neutral-grounding transformers and reactors than it is with small potential transformers, it is still important to consider the inrush that occurs at the onset of a ground fault. Transformer inrush can be 12 to 14 times more than the transformer's full-load current for 0.1 seconds, which can result in excessive ground-fault voltage.

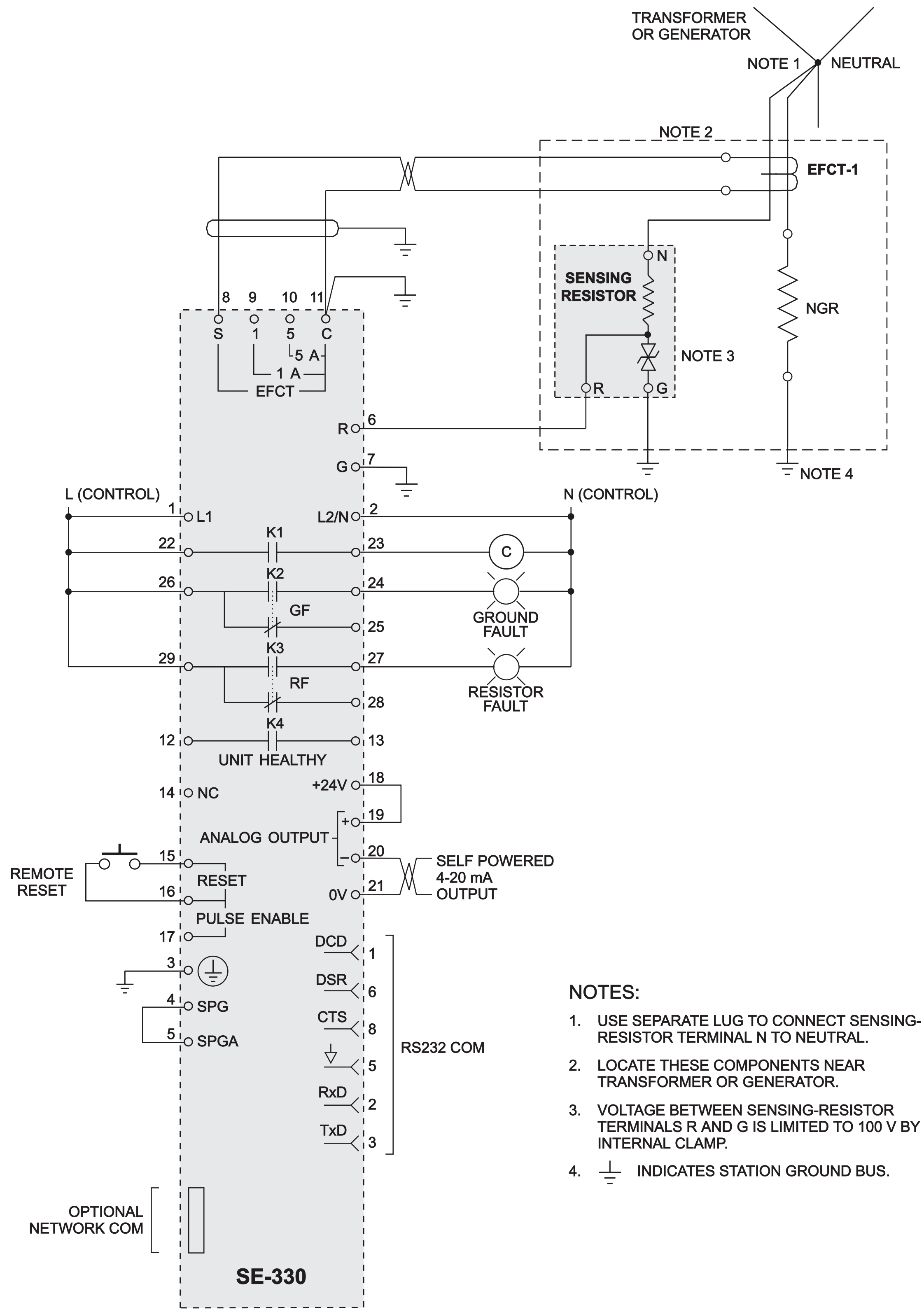
Adjustable-speed drives and solid-state starters are increasingly being used in industrial systems. Non-triplen harmonic voltages that result cause harmonic currents to flow in the ground conductor if harmonic voltages or capacitive reactances are not balanced. Triplen harmonics are in phase and where triplen harmonic voltages are present, the current will flow in the ground conductor and the NGR. An NGR monitor must either be set above the operating harmonic level or not be affected by harmonics. While the ideal monitor is a non-contact device, solutions that involve connecting elements in parallel with the NGR are practical.

Elements connected to the NGR are subject to line-to-neutral ground-fault voltages and must be evaluated in all failure modes. Resistors and inductors fail open, although turn-to-turn shorting can occur during failure. Capacitors can fail in open or in short. Any capacitive or inductive coupling technique should be investigated with respect to ferroresonance and excessive ground-fault voltage. Coupling devices must not transfer hazardous voltages to any associated monitoring equipment.

Atmospheric electrical conditions, such as the presence of charged clouds, can affect an electrical substation feeding overhead lines. Any NGR monitor used in this application must be immune to these conditions.

Monitor NGR connections to the neutral and to the ground bus. **Figure 4** shows a typical application of an NGR monitor with a sensing resistor connected to the neutral. The NGR monitor measures the changes in NGR resistance, the current in the neutral, and neutral-to-ground voltage. The NGR monitor coordinates these three measurements and operates output contacts when an NGR fault or a ground fault is detected. The output contacts can be used to trip the main breaker or to operate annunciation devices.

The measurements made by an NGR monitor can be useful when evaluating system problems. An analog signal can meter local earth-leakage currents. An NGR monitor with a communications interface enables data access from a local PC or a network.



NOTES:

1. USE SEPARATE LUG TO CONNECT SENSING-RESISTOR TERMINAL N TO NEUTRAL.
2. LOCATE THESE COMPONENTS NEAR TRANSFORMER OR GENERATOR.
3. VOLTAGE BETWEEN SENSING-RESISTOR TERMINALS R AND G IS LIMITED TO 100 V BY INTERNAL CLAMP.
4. ⏚ INDICATES STATION GROUND BUS.

Figure 4. Typical NGR monitor application.

NGR MONITOR DESIGN REQUIREMENTS

NGR monitoring considerations can be summarized in terms of their design requirements:

- The monitor must not create a hazard with respect to ferroresonance or ground-fault voltage.
- The monitor should not affect ground-fault coordination. If ground-fault protection is to be incorporated into the NGR monitor, then the operating values, sensitivity to harmonics, and coordination delays must be compatible with downstream devices.
- The monitor should be designed to operate in the undervoltage mode so that the output relay is energized when the monitor is not tripped. This is the fail-safe mode. Although the fail-safe mode is preferred, provision should be made for shunt-trip operation.
- The monitor must be capable of detecting an NGR failure that occurs subsequent to a ground fault, but prior to ground-fault tripping, or detect an NGR failure in an alarm only system. Continuity through a fault must not be confused with NGR continuity.
- The monitor must be capable of detecting a ground fault subsequent to an open NGR failure as NGR failure renders down-stream current-based ground-fault protection, coordination, and annunciation systems inoperative.

SUMMARY

Sensing resistors with higher voltage ratings enables the use of the same monitor for a wide range of low and medium voltage systems. Neutral voltage must be measured to detect an NGR failure during a ground fault or a ground fault during an open NGR failure. Monitors must also trip if neutral voltage is sustained above the product of the operating value of the ground-fault circuit and the resistance of the NGR. With the voltage-measuring circuit already incorporated, an NGR-resistance set point is not necessary and an NGR-resistance trip level is sufficient. Further development allows resistance calibration to individual NGRs and provides a means to detect a reduction in NGR resistance. An NGR monitor provides protection against failures that previously rendered protection, coordination and annunciation systems inoperative, or allowed higher prospective levels of ground-fault current. The integration of ground-fault detection adds primary or backup ground-fault protection.

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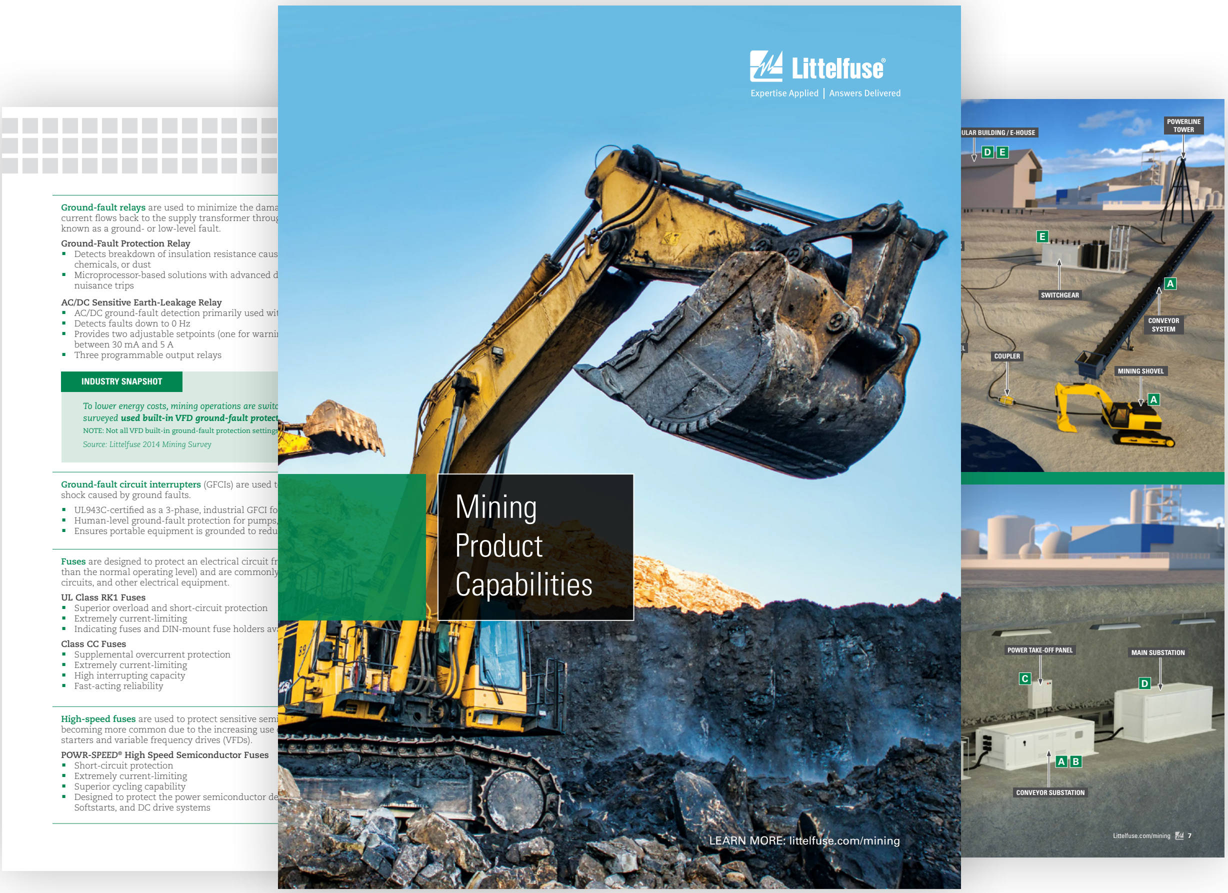

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